Industrial Health 2016, **54**, 296–307

Original Article

The influence of vibration on seated human drowsiness

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Received May 15, 2015 and accepted January 15, 2016

Abstract: Although much is known about human body vibration discomfort, there is little research data on the effects of vibration on vehicle occupant drowsiness. A laboratory experimental setup has been developed. Vibration was applied to the volunteers sitting on the vehicle seat mounted on the vibration platform. Seated volunteers were exposed to a Gaussian random vibration, with 1–15 Hz frequency bandwidth at 0.2 ms^{-2} r.m.s., for 20-minutes. Two drowsiness measurement methods were used, Psychomotor Vigilance Test (PVT) and Karolinska Sleepiness Scale (KSS). Significant changes in PVT ($p<0.05$) and KSS ($p<0.05$) were detected in all eighteen volunteers. Furthermore, a moderate correlation ($r>0.4$) was observed between objective measurement (PVT) and subjective measurement (KSS). The results suggest that exposure to vibration even for 20-minutes can cause significant drowsiness impairing psychomotor performance. This finding has important implications for road safety.

Key words: Human vibration, Ride comfort, Drowsiness, Sleepiness, Psychomotor-vigilance test (PVT), Karolinska sleepiness scale (KSS)

Introduction

Falling asleep at the wheel or drowsy driving is a significant cause of accidents on motorways or major roadways[1]. Drowsy driving has been reported to account for approximately 20% of accidents worldwide[1]. In Australia, there were 251 fatalities (16.6% of total road deaths) caused explicitly by sleep-related accidents in 1998 alone[2].

In addition to that, a new EU regulation about sleepiness in driving with a focus on sleep apnoea patients has been issued. Drivers or driving licence applicants with moderate and severe obstructive sleep apnoea shall be referred for further medical advice before a driving license is granted or renewed[3]. It is well established that drowsiness caused by extended hours of driving has considerable influence on driver performance, therefore, compromising transportation safety[4]. Although some research have demonstrated the is a possible link between short-term exposure to vibration and reduction of wakefulness level[5, 6], however, drowsiness caused by vibration is not well investigated and characterized in the available literature. Hence, automotive industry standards to limit vibration-induced drowsiness

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do not as yet exist.

In the automotive industry, vehicle seat structure is exposed to vibration from various sources such as vehicle powertrain and road surface. Fundamental vibration modes (resonant frequency and correspondence mode shapes) of automotive body which can transmit vibration to the seat structure occur at a frequency below 60 Hz[7)]. However, the fundamental resonance of the human body occurs at a frequency below 15 Hz[8)]. It is well known that vibration that is transmitted to the seated human body has a significant influence on human perception and ride comfort[8–10)]. ISO 2631-1 (1997)[11)] International Standard for evaluation of human exposure to whole-body vibration has been used successfully for several years. Although this International Standard (ISO 2631-1) has been developed for the assessment of human body discomfort that is called "Equivalent Comfort Contour", however, there is little quantitative knowledge of how vibration causes drowsiness.

Hence, there is considerable scope for defining the exact effects of vehicle and particularly seat vibration on seated human drowsiness levels. No particular attempt has yet been made to rank the factors that contribute to drowsiness in their order of importance. Therefore, we focused on drowsiness caused by vibration only. Drowsiness or sleepiness is a transitory period between being awake and asleep[12)]. Various studies have suggested that drowsiness affects our daily functioning and our physical and mental health[13, 14)]. According to the literature, drowsiness or a state of near-sleep can be quantified in many ways[15)]. One of the most reliable methods to predict drowsiness, as used in sleep deprivation and performance research, is the psychomotor vigilance task (PVT)[16, 17)]. PVT requires a response to a visual stimulus by pressing a response button as soon as the stimulus appears. Research consistently shows that cumulative sleep restriction and drowsiness results in an increase in reaction time, a decrease in response speed (1/RT), and an increase in the number of lapses (RT>500 ms)[18–24)]. Although many studies have attempted to demonstrate the links between PVT performance and drowsiness, drowsiness caused by vibration has not been experimentally assessed by PVT. Therefore, it was also important to investigate the feasibility and utility of PVT in the detection of drowsiness caused by vibration. Hence, it was the primary aim of this study to investigate the effects of vibration on human drowsiness level using both objective (PVT) and subjective (KSS) measurement methods.

Subjects and Methods

Subjects

Volunteers for this investigation included eighteen young male and healthy university students (mean age±SD: 23.0±1.3 years). The average height was 168.2±4.0 cm and weight 64.2±12.2 kg. The average BMI of volunteers was 22.6±2.54 kg/m^2. None of the volunteers had a history of neck pain, diseases of the cervical spine or musculoskeletal disorders. They had normal hearing and normal or corrected-to-normal vision. One week prior to laboratory experiment, volunteers were required to maintain their normal amount of sleep (between 7 and 9 h) and keep a normal sleep schedule. Therefore, they were asked to keep a sleep diary of when they go to sleep at night and wake up each day. Volunteers were also screened using the Epworth Sleepiness Scale (ESS) to detect any abnormalities in sleepiness[25)]. The total ESS score ranged from 0 to 24; scores below 7 were considered as normal, scores between 8 to 10 as moderate sleepiness, scores between 11 to 15 was applied to define an elevated risk, whereas scores above 16, severe excessive daytime sleepiness (EDS)[26)], was considered as high risk of falling asleep in various monotonous situations[27)]. Subjects with a score >7, indicating moderate to excessive sleepiness were excluded from the experiment[28)].

Ethical considerations

Volunteers were provided with verbal and written explanations of the purpose of the experiment. Participation in the experiment is a voluntary basis. Therefore, volunteers have right to refuse participation, and the results of the experiment would remain confidential. The informed written consent form was obtained from all the volunteers after the procedure of the experiment was explained, and the laboratory facilities were introduced to them. The experimental protocol was reviewed and approved by the RMIT University Human Research Ethics Committee (Approval Number: EC 00237).

Apparatus

The experiment set-up for drowsiness assessment is illustrated in Fig. 1. The seat used for the experiments is a mid-sized sedan car seat with adjustable headrest. The seat was mounted on a cast aluminium table (2 m×1.2 m×1.2 m), and the table was mounted on four air mountings (regulated to 20 psi). The seat's inclination angle was set at 15° to the vertical direction. Experiment set-up has been developed with a single vertical hydraulic actuator to replicate

Fig. 1. A human vibration simulator was designed for this study. An actual vehicle's seat was mounted on a vibration table. Hydraulic actuator located at the corner of the table will provide multi-axial input to the volunteer. Volunteer was asked to take a seat and assume a comfortable position with their hands on the lap. Feet were placed on the footrest to isolate the vibration from the floor.

the vibration perceived by seated occupant in a moving vehicle. Although, the input vibration was not independent on each axis. However, the input vibration generated from the hydraulic vertical actuator is located below the table away from the centre of the table. The off-centre excitation provides the multi-axial (x, y, z-axis) input vibration. This vibration setup also was built to be somewhat similar to the vibration that is transferred from the vehicle floor to the seat. The vibration table below the seat was designed to be dynamically rigid in frequencies below 100 Hz. This is to ensure that there is no interaction with vehicle seat structural dynamics. The time and environment of the experiments are chosen so that the noise level were same for different test conditions. In order to minimize any possible effects of noise on the results of this study, care was taken to run all experiment in similar noise conditions. Prior to drowsiness measurement, measurement of total transmitted vibration (seat pan and backrest) to each volunteer have been done in accordance with ISO 2631-1 (1997) and used the method reported by Fard *et al.*[11, 29]. The measurement was carried out to adjust the required hydraulic input force for every volunteer to become 0.2 ms^{-2} r.m.s.

Two tri-axial accelerometer pads (SVANTEK SV-38V model) were used to measure the transmitted vibration to the human volunteer body at both seat cushion and the seatback[29]. This magnitude was calculated according to ISO2631-1 (1997) International Standard, which represents a total transmitted vibration value measured from the transducer or accelerometer pad that was placed at the interface between seat supporting surface (seat cushion and seatback) and human interface. The SV 106 human vibration exposure (HVE) meter (analyser), which was connected to the accelerometer pads, was used to obtain the total frequency weighted transmitted vibration to the seated human body. The HVE analyser uses the weighting factors (W_k, W_d, W_c) and multiplication factors (Table 1) to calculate the total frequency-weighted transmitted vibration to the seated human body. The weighting curves(W_k, W_d, W_c) given in Table 1 were from ISO 2631-1 (1997)[11]. The frequency weighting curves define the values by which the vibration magnitude at each specific frequency is to be multiplied in order to weight the measured vibration in accordance with the human body[8]. The multiplication factors (Table 1) were used to weight the effects of seatback and seat pan vibrations on the ride comfort assessment[11, 29].

Table 1. The frequency weighting coefficients and the multiplication factors, from ISO 2631-1 (International Organization for Standardization, 1997) standard, corresponding to X (fore-aft), Y (lateral), and Z (vertical) accelerations in the seat cushion and the seatback. W_k, W_d, W_c are shown here.

	Seat Accelerometer Pad					
	Seat cushion			Seatback		
Axis	X	Y	Z	X	Y	Z
Weighting	W_d	W_d	W_k	W_c	W_d	W_d
Multiplication factor k	1	1	1	0.8	0.5	0.4

Experimental procedures

The experiment was carried out in a temperature and light controlled (21°C–23°C, <70 lux) laboratory and the noise level was below 60 dB. Volunteers arrived at the laboratory at 8.00 h after a normal night's sleep and light breakfast. They were required to not consume any alcoholic or caffeinated beverages. Volunteers were required to complete an initial screening session to assess their fitness for inclusion in the study. The experiment began at 8.30 h. All volunteers were subjected to two experiment conditions (with-vibration and no-vibration). These two conditions were performed over two separate days. The orders of two conditions were randomly ordered to avoid order-related influences.

Vigilance was assessed with the PC-based Psychomotor Vigilance Test (PVT-192: Ambulatory Monitoring Inc., Ardsley, New York)[30], a 10-minutes visual reaction time (RT) task that evaluate sustained attention in two conditions; before vibration exposure and after vibration exposure. The 10-minutes PVT has become the most widely

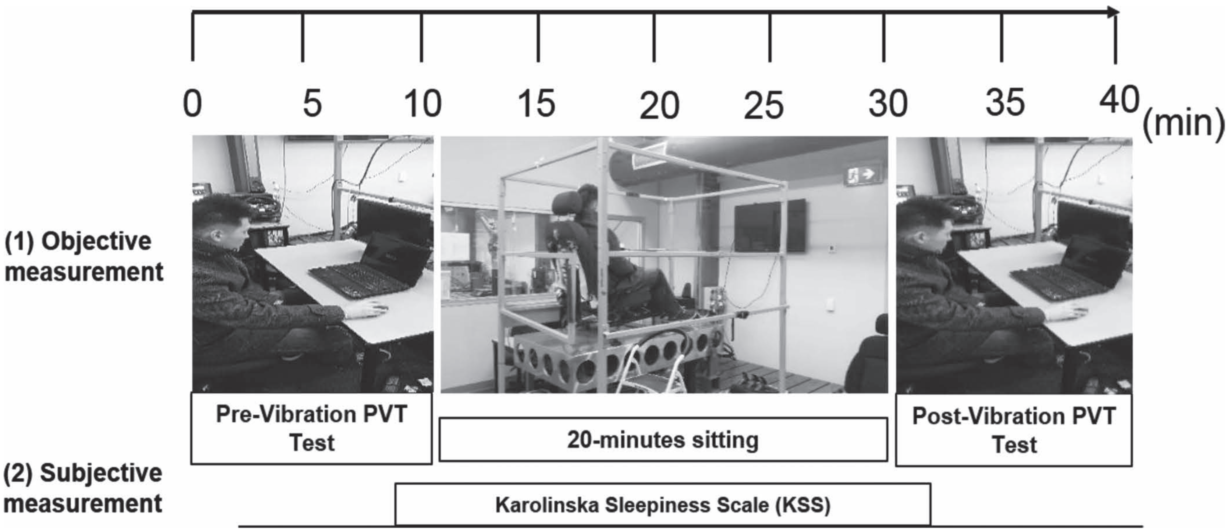

Fig. 2. The two drowsiness assessment methods are illustrated; the objective psychomotor vigilance test (PVT) and the subjective Karolinska Sleepiness Scale (KSS). The PVT was assessed before and after 20-minutes of vibration. Subjective evaluation was administrated before vibration, every 5-minutes of vibration and after 20-minutes of vibration exposure. Similarly, the subjects were tested after 20-minutes of no-vibration exposure.

used measure of neurobehavioral test and has shown to be sensitive to both acute and total sleep deprivation[28]. In this PVT test, volunteers were instructed to respond to the onset of a visual millisecond counter by clicking a mouse as quickly as possible. The stimulus was a red light emitting diode displaying time in milliseconds. The light remains visible and stops counting immediately at the subject response. During each 10-minutes session, visual stimuli appeared the variable intervals of 2–10 second. From each PVT condition, six PVT performance metrics; minor lapse (response time >500 ms), mean RT, median RT, response speed 1/RT, fastest 10% RT, slowest 10% RT, were extracted using a software program. According to literature[31], The reciprocal transform (1/RT) or response speed was one of the PVT performance metrics found to be sensitive to total and partial sleep loss[31]. A response is considered valid if it is >100 ms[31]. A response less than 100 ms indicates a false signal or error of commission[31]. To minimise the learning effect, volunteers completed three practice sessions before the real test as the previous study shows that the PVT has 1–3 trial learning curve[32].

During vibration condition, volunteers were asked to sit comfortably with their eyes open, their back on the backrest and hands on their lap. The volunteers were required to sit with their feet firmly placed on the footrest as shown in Fig. 2. The footrest was not connected to the vibration table and was isolated from the vibration. Volunteers were also instructed to limit any physical movement. Then, volunteers were exposed to a Gaussian random vibration, with 1–15 Hz frequency bandwidth, for 20-minutes. Previous research has shown evidence that even exposure to vibration for only 12-minutes may cause reduction of wakefulness level[5]. Total transmitted acceleration to the human body was kept constant at 0.2 ms^{-2} r.m.s. Volunteers rated their subjective sleepiness using Karolinska Sleepiness Scale (KSS) before vibration exposure, every 5-minutes of vibration and after vibration exposure[33]. The use of the scale had been practiced beforehand and consisted of the following scores: 1=extremely alert, 2=very alert, 3=alert, 4=rather alert, 5=neither alert or sleepy, 6=some sign of sleepiness, 7=sleepy, but no effort to stay awake, 8=sleepy, some effort to stay awake, 9=very sleepy, great effort to stay awake. No conversation was permitted between the volunteer and the test leader unless in the event of an emergency. Similar procedures and sitting arrangement as in with-vibration condition with the only difference being no vibration exposure were applied for the no-vibration condition. Volunteers were required to take a seat for 20-minutes after completing first PVT test. Second PVT test was conducted immediately after 20-minutes of sitting.

Statistical analysis

Statistical analysis was performed using GraphPad software (GraphPad Prism 6). All data were checked for normality prior analysis. Changes in PVT performance metrics (minor lapse, mean RT, median RT, response speed 1/RT, fastest 10% RT, slowest 10% RT) for both conditions

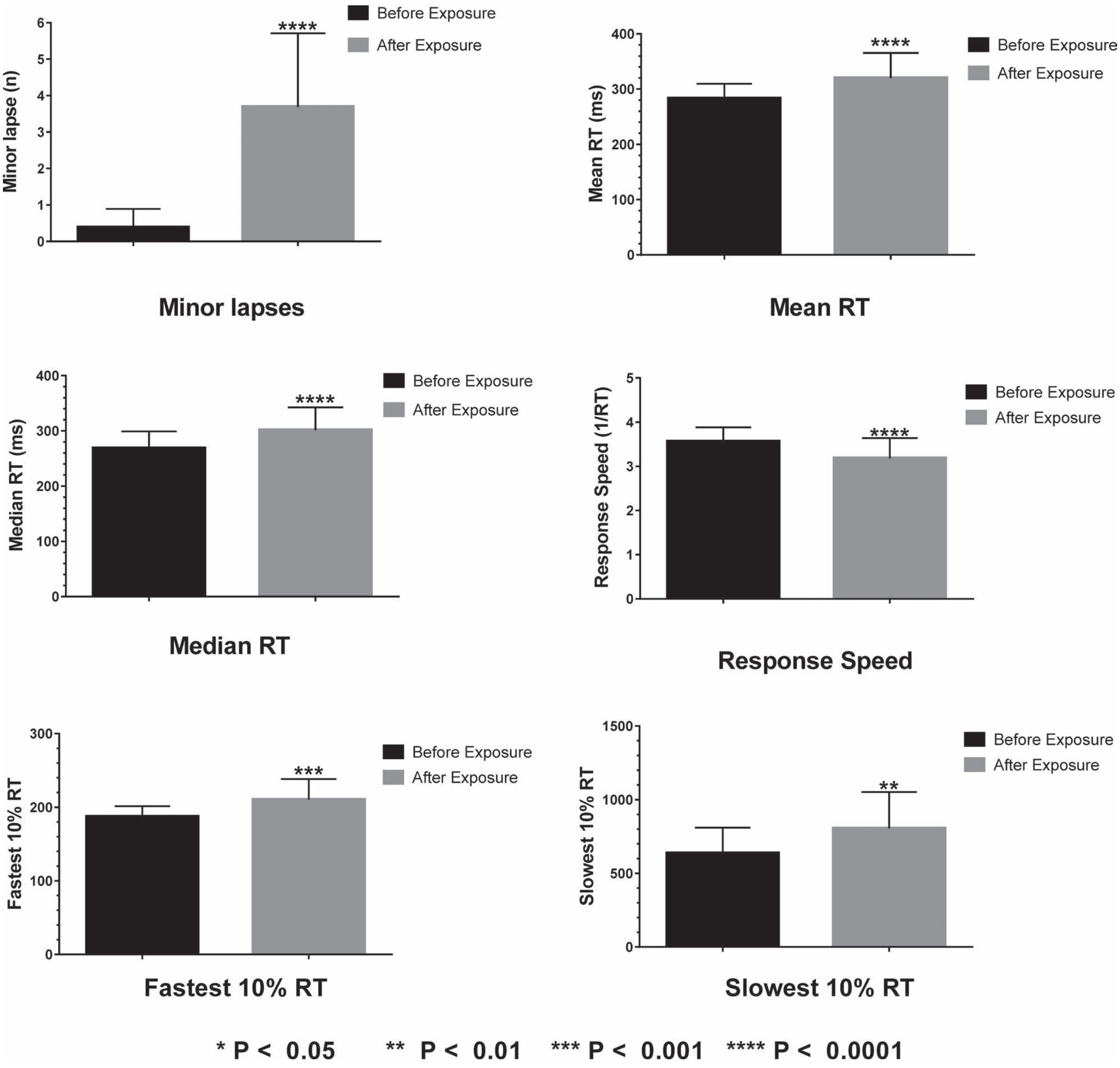

Fig. 3. Statistically significant changes ($p<0.05$) of six PVT metrics (mean ± SD) before and after 20-minutes exposure to vibration were observed for all eighteen volunteers. The changes indicate PVT impairment due to drowsiness caused by exposure to vibration.

(with-vibration and no-vibration) were verified by Paired t-test comparison. Mean RT values were reciprocally transformed to mean 1/RT to normalize the data. Error bars in the figure indicate standard deviation (SD) of the average values. Two-tailed ($p<0.05$) was considered statistical significance. Effect sizes were calculated to determine the magnitude of the differences between two variables. These values were calculated as the average of the within-subject difference divided by the standard deviation of the within-subject difference. Therefore, effect sizes increase with the magnitude of within–subject difference and decrease with increasing variability of the differences. Effect sizes above 0.8 indicate substantial statistical and clinical difference. Effect sizes above 0.5 indicate moderate statistical and clinical differences[34]. Two-way repeated measures - Analysis of Variance (ANOVA) was used to assess the changes in subjective sleepiness over the course of vibration exposure. All post hoc testing was performed via the Tukey post-hoc test. Correlation between the objective measure and subjective measure was calculated using Pearson's r correlation coefficient.

Results

Objective measurement—Psychomotor Vigilance Test (PVT)

Influence of vibration on human drowsiness level, measured by PVT, is shown in Fig. 3. The following six

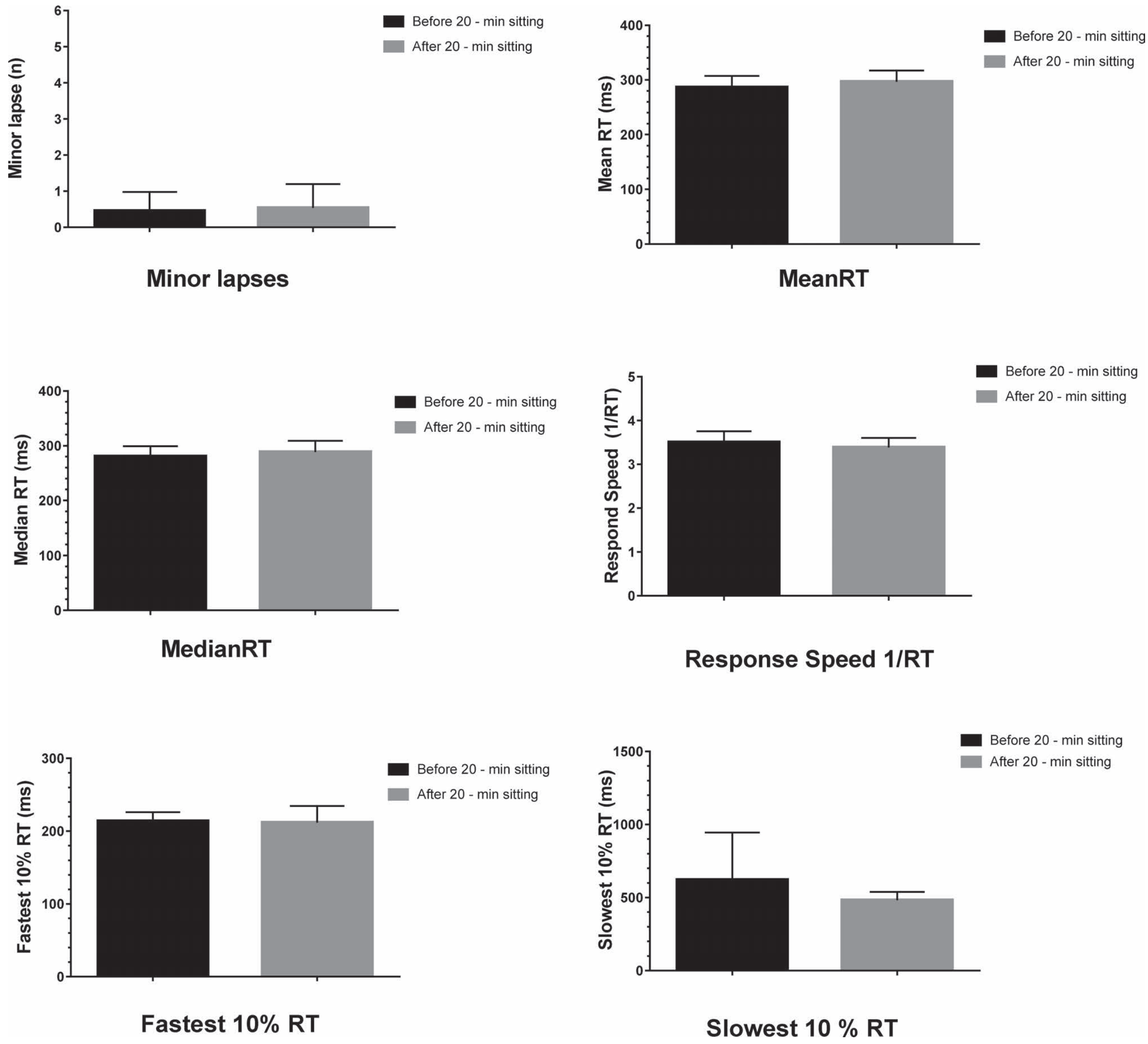

Fig. 4. No statistical significance changes of six PVT metrics (mean ± SD) before and after 20-minutes sitting were observed in no vibration condition in all eighteen volunteers ($p > 0.05$). This indicates 20-minutes sitting does not sufficient to induce drowsiness to the volunteers.

PVT metrics were assessed and included in the analyses: (1) minor lapse, (2) mean RT (RT), (3) median RT, (4) response speed 1/RT, (5) fastest 10% RT, (6) slowest 10% RT. Each panel of Fig. 3 shows the average and standard deviation (SD) of each PVT metric before exposure and after 20-minutes of exposure to vibration. Comparison of the six PVT metrics before exposure and after exposure to vibration showed that the 20-minutes exposure to vibration had significant influences on volunteer's RT. Significant increases of reaction time and increases in the number of lapses were found in all eighteen volunteers. We found that following 20-minutes exposure to vibration, the average number of PVT lapses or RT >500 ms (mean ± SD) across eighteen volunteers was increased from (0.38 ± 0.14 to 3.69 ± 0.56 ($p < 0.05$). This substantial increase indicated a significant decreased in alertness level.

A statistically significance increase in reaction time could also be seen in mean RT. Due to exposure to vibration, volunteers' mean RT was increased by 13% from (mean ± SD: 283.1 ± 6.24 to 320.2 ± 0.56; $p < 0.05$). In addition, drowsiness also impairs median RT. There was an increase of 12 % from (mean ± SD: 268.5 ± 7.21 to 301.3 ± 9.58; $p < 0.05$) in median RT following exposed to vibration. To normalize the data distribution, the average reaction time was reciprocally transformed to mean 1/RT. This metric is known as response speed. Significance decreases of response speed could be observed in all eighteen volunteers (mean ± SD: 3.561 ± 0.07 to 3.182 ± 0.11; $p < 0.05$).

Other PVT metrics that were measured were fastest 10%

Table 2. Comparison of mean change in PVT metrics between 'No-Vibration condition' and With-Vibration condition' is shown. It clearly can be observed that, there were a substantial changes in reaction time of all PVT metrics in with-vibration condition compared to no-vibration condition. $P-$value are calculated between 'No-Vibration condition' and With-Vibration condition.

PVT Metrics	No-Vibration Condition		With-Vibration Condition		$P-$Value
	Before 20-min sitting (mean±SD)	After 20-min sitting (mean±SD)	Before 20-min exposure (mean±SD)	After 20-min exposure (mean±SD)	
Minor Lapse (n)	0.46±0.14	0.54±0.18	0.38±0.14	3.69±0.56	<0.05
Mean RT (ms)	286.6±7.90	296.6±7.87	283.1±6.24	320.2±10.68	<0.05
Median RT (ms)	280.6±6.91	288.6±7.64	268.5±7.21	301.3±9.68	<0.05
Response Speed	3.50±0.09	3.38±0.08	3.561±0.07	3.18±0.11	<0.05
Fastest 10% RT (ms)	213.9±4.62	211.7±8.62	187.2±3.34	210.3±6.60	<0.05
Slowest 10% RT (ms)	621.4±122.10	481.6±21.40	637.9±40.77	805.1±58.20	<0.05

RT and slowest 10% RT. It can be seen from the Fig. 3 that the fastest 10% RT was significantly worse by 11% and the slowest 10% were significantly increase by 26% following exposure to vibration (mean±SD: 210.3±6.60; $p<0.05$ and mean±SD: 805.1±58.20; $p<0.05$, respectively). To verify the PVT results of vibration condition, paired *t*-tests were used.

It should be noted that, in the absence of vibration, no significant changes were observed in PVT metrics ($p>0.05$) after 20-minutes sitting. Comparisons of six PVT metrics (mean±SD) for before and after 20-minutes sitting were shown in Fig. 4. The results show that 20-minutes of sitting with no exposure to vibration does not have any considerable effects on drowsiness. Volunteers' RT performance have not demonstrated any considerable changes. Consequently, the observed drowsiness in the presence of vibration were mainly induced by vibration.

Comparison of mean change between 'No-Vibration' and 'With-Vibration' condition were shown in Table 2. This is to determine the real change of drowsiness level caused by vibration. Mean change in drowsiness is significantly greater under vibration than a no-vibration condition in all PVT metrics. To verify the result, $p-$value for all PVT metrics are calculated and shows statistically significant difference in vibration condition as compared to no vibration condition ($p<0.05$).

To determine the magnitude of the differences between before and after vibration exposure, effect sizes for all PVT metrics were calculated and are shown in Table 3. The effects sizes were adjusted for the no-vibration condition differences and variability. Therefore, effect sizes increase with the magnitude of within−subject difference and decrease with increasing variability of the differences. Based on the above definitions, PVT metrics were arranged according to their effect sizes and sensitivity to vibration. As can be seen in Table 3, minor lapse showed larger magnitude (ES=0.75) of the difference between no-vibration and with-vibration condition that indicated stronger sensitivity to vibration followed by mean RT (ES=0.45), response speed 1/RT (ES=0.43) and median RT (ES=41). Effect sizes more than 0.5 indicates moderate statistical and clinical difference between two variables. Small effect sizes (ES>0.2) were observed for the slowest 10% RT and fastest 10% RT. It represents a small statistical and clinical difference between two groups. Therefore, based on the finding of these analyses, minor lapse which has high effect sizes (ES=0.75) can be considered as the primary PVT metrics and it is consistent with literature to be the most commonly used outcome metrics because of high sensitivity to sleepiness[31].

Table 3. Effect sizes were calculated and adjusted to no-vibration condition to determine the magnitude of the differences of six PVT metrics in only vibration condition. All six PVT metrics have been arranged according to their effect sizes. Minor lapse or RT>500 ms shows larger effect sizes (ES=0.75) followed by mean RT (ES=0.45). Effects size more than 0.5 represents a moderate statistical and clinical difference between two groups. Effect size more than 0.2 represents a small statistical and clinical difference between two groups

Rank	Outcome Metrics	Cohen's D	Effect Size (ES)
1	Minor lapse	2.25	0.75
2	Mean RT	1.00	0.45
3	Response Speed 1/RT	0.97	0.43
4	Median RT	0.91	0.41
5	Slowest 10% RT	0.75	0.35
6	Fastest 10% RT	0.54	0.27

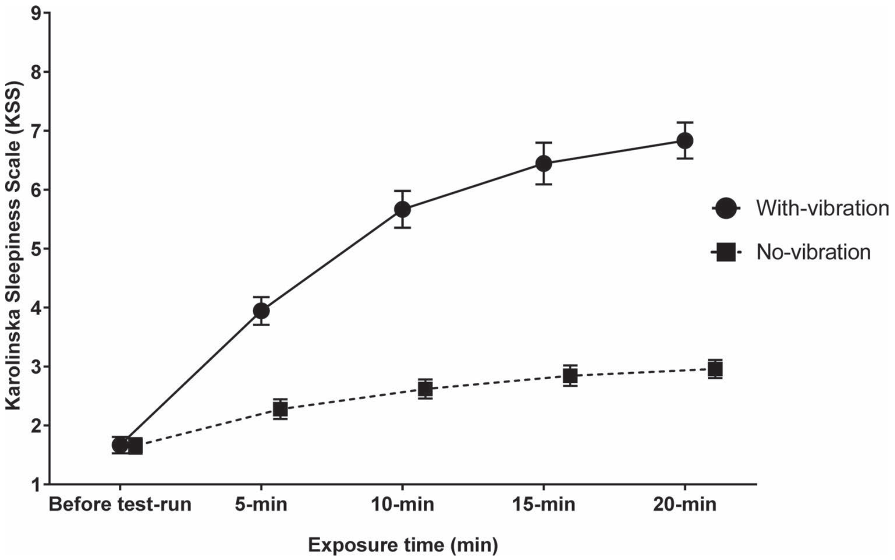

Fig. 5. The average±SD of Karolinska sleepiness scale scores (KSS) for all the volunteers from before test-run, during and after 20 minute in with-vibration and no-vibration condition are shown. The KSS score consist of the following scores: 1=extremely alert, 2=very alert, 3=alert, 4=rather alert, 5=neither alert or sleepy, 6=some sign of sleepiness, 7=sleepy, but no effort to stay awake, 8=sleepy, some effort to stay awake, 9=very sleepy, great effort to stay awake. It clearly can be observed that, there was greater increase on drowsiness level in with-vibration condition compared to no-vibration condition, and the increase is statistically significant ($p<0.05$).

Subjective measurement—Karolinska Sleepiness Scale (KSS)

Subjective sleepiness (KSS score was plotted against time and is shown in Fig. 5. Significant increases of KSS score between before vibration exposure and every subsequent 5-minutes of exposure to vibration were detected for all eighteen volunteers. Figure 5 shows a clear decline in alertness level indicated by a progressive increase in subjective sleepiness score throughout the course of exposure to vibration. Before vibration exposure, the average KSS score was 1.67±0.14 (mean±SD). After 5-minutes of vibration exposure, KSS scores increased to 3.94±0.24 (mean±SD). Drowsiness was pronounced after 15-minutes exposure to vibration with KSS values of 6.44±0.35 (mean±SD). According to Fig. 5, it should be noted that even 15-minutes exposure to vibration induced drowsiness to the volunteers and the drowsiness were more pronounced with exposure to vibration for a period longer than 15-minutes. To investigate statistical significance, two-way repeated measures-ANOVA corrected for Turkey's multiple comparison was carried out.

It should be noted that, in the absence of vibration, no significant changes were observed in KSS after 20-minutes sitting. KSS results for before and after 20-minutes sitting with no-vibration have been shown in Fig. 5. The KSS score was (mean±SD: 1.78±0.13) before 20-minutes of sitting. Only a slight increases in subjective sleepiness scale (mean±SD: 3.06±0.15) were observed after 20-minutes of sitting (Table 4). Tukey's HSD tests showed that exposure to vibration had significantly influence on human drowsiness level. The main effect of intra-individual was significant, ($F(4,68)=136.3$, $p<0.01$), as was the main effect of inter-individual, ($F(17,68)=7.81$, $p<0.01$). This is similar to PVT results, and it shows that the observed drowsiness was mainly induced by vibration.

Table 4. Table shows an average score of subjective sleepiness scale (KSS) for eighteen volunteers for five interval session in no-vibration compared to with-vibration condition. Before exposure and sitting, no significant changes were observed for both condition ($p>0.05$). However the subjective sleepiness scale for all volunteers shows a significant increase following exposure to vibration ($p<0.05$). This indicates a reduction in alertness level due to vibration exposure.

Karolinska Sleepiness Scale (KSS)	No-Vibration (mean±SD)	With-Vibration (mean±SD)	$P-$Value
Before test-run	1.78±0.13	1.67±0.14	$p>0.05$
After 5 minutes	2.39±0.16	3.94±0.24	$p<0.05$
After 10 minutes	2.72±0.16	5.67±0.31	$p<0.05$
After 15 minutes	2.94±0.17	6.44±0.35	$p<0.05$
After 20 minutes	3.06±0.15	6.83±0.30	$p<0.05$

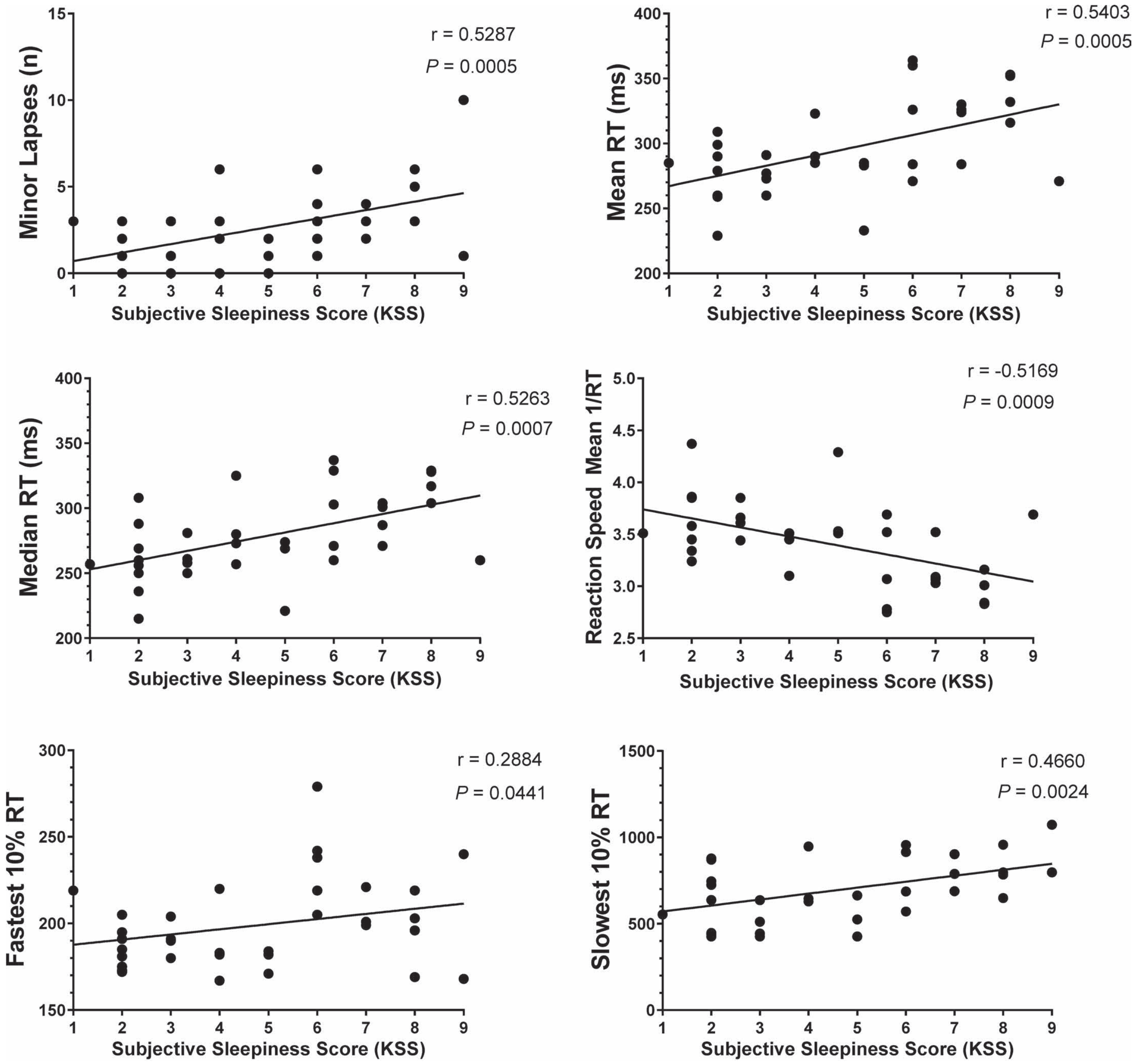

Fig. 6. Figure shows the correlation between six PVT metrics and subjective sleepiness Scale score (KSS) for all eighteen volunteers. KSS and PVT score before the test-run and after 20-minutes of the vibration exposure were used to determine the correlation between KSS and PVT. Moderate correlation (r>0.4) between objective measurement (PVT) and subjective measurement (KSS) can be observed in all PVT metrics except in fastest 10% RT (r=0.28).

Correlation

Furthermore, we interrogated the correlation between subjective (KSS) and objective (PVT) findings of this study by the use of Pearson's (r) correlation. KSS scores before and after 20-minutes exposure to vibration were used to determine the correlation with PVT. Figure 6 demonstrates a moderate positive correlation (r=0.4–0.55) between these measures, except lower for the fastest 10% RT (r=0.28). A positive correlation indicates that impairment in reaction time was related to subjective self-reported sleepiness, and the relationship was statistically significant ($p<0.05$), albeit moderately strong.

Discussion

The present study was designed to determine the relationship between seated human drowsiness levels and exposure to vibration as can be experienced in a vehicle. As mentioned in the introduction, drowsiness has been one of the primary causes of road accidents[1]. However, drowsiness that is caused by vehicle vibration is not well understood or investigated.

We demonstrated that the increase of human drowsiness level, measured by the six performance metrics of the PVT test and subjective sleepiness rating significantly correlated with exposure to vibration. These data support the hypothesis that exposure to vibration (random vibration with 1 – 15 Hz frequency band) even for as little as 20-minutes causes drowsiness and adversely affects psychomotor performance as measured by reaction time and increases lapses of attention, both found in all eighteen volunteers. High effect sizes were observed for minor lapse (ES = 0.75) which indicate large statistical and clinical differences between no-vibration and with-vibration condition. Together these findings also suggest a high degree of sensitivity for PVT metrics (mean RT and response speed 1/RT), in detecting a vibration-induced decline in alertness. It has also been reported that reaction time impairment is the most common and persistent finding in sleep deprivation and drowsiness[24, 35)]. Our results demonstrate, for the first time that exposure to whole-body vibration is a possible mechanism for reaction-time impairment. Together these changes in RT values indicated that exposure to as little as 20-minutes of vibration reduced human alertness levels and induced significant drowsiness. This induced-drowsiness caused by vibration influenced the volunteers' ability to respond quickly to visual stimuli. Another significant finding to emerge from this study is that PVT showed high levels of sensitivity to whole body vibration-induced changes in human drowsiness.

As expected, results from subjective measurement (KSS) also shows a significant declination of alertness level for all the volunteers after 20-minutes exposure to vibration. Increases in subjective sleepiness scores provide important corroborating evidence that exposure to 20-minutes of vibration level can steadily reduce human alertness levels that are linked to drowsiness.

In a study which set out to determine the influences of exposure to whole-body vibration on the wakefulness level, Landstrom *et al.* exposed the volunteers to a low frequency sinusoidal and random vibration in the vertical direction at 0.3 ms^{-2} r.m.s.[36)]. A significant increase in theta and decrease in alpha activity were observed indicating a decrease in wakefulness level following exposure to vibration. However, the effect is more pronounced in sinusoidal vibration than random vibration. Although the transmitted vibration used in their study is differed from those used in our study, their findings are consistent with ours. The findings observed in our study also mirror those of the previous studies that have examined the effect of short-term exposure to whole-body vibration in human[5, 6)]. Although no significant difference was observed in subjective wakefulness level using KSS, regardless with or without exposure to vibration, a significant decrease of wakefulness level was detected in objective wakefulness level during vibration exposure. These findings are in agreement with our study which showed short-term exposure to vibration for 20-minutes can cause a reduction in wakefulness level.

Various methods have been proposed in the past to assess human drowsiness and performance, such as measuring brainwave activity using electroencephalography (EEG)[12, 37–39)]. EEG method has the ability to measure changes in brainwave power spectrum. However, the implementation of EEG in the real environment is still challenging. Brainwave activity signals measured by the electrode on the human scalp can be easily distorted by movement artefacts such as muscle activity and eye-movements[40)]. Placement of EEG electrodes may be uncomfortable and, therefore, impracticalms[12, 41, 42)]. Hence, an alternative method that is more reliable and accurate and suits driving conditions needs to be selected for these studies. PVT was preferred to EEG method as it was reliable, practical, extensively characterised and had a high degree of sensitivity to changes in alertness[16, 43, 44)]. In addition, PVT displays minimal learning effects that make it an ideal research instrument[32)].

Experiment design has been developed with a single vertical hydraulic actuator to replicate the vibration perceived by seated occupant in a moving vehicle to the extent possible under laboratory conditions. Although, it was not independent on each axis, however, vibration generated from the table is somewhat similar to floor vibration in a vehicle. This vibration excitation method has been designed by Fard *et al.*[29)] for analysing the effects of vibration on comfort. More advanced vibration simulator with independent actuators may further improve the multi-axial quality of input vibration. Moreover, this work does not consider the vibration frequency range above 15 Hz. This limited frequency band is selected to improve the measures of drowsiness-inducing vibration and focus on a narrow frequency band. Furthermore. several studies also have suggested that vehicle seat's resonance frequency and corresponding mode shapes occur at a frequency above 15 Hz[29)]. Therefore the frequency of vibration limited to 1 – 15 Hz in this study to ensure that there is no interaction of vehicle seat's dynamics (resonance frequency and corresponding mode shapes) with the total transmitted vibration to human body measured from seat pan and seat backrest. Although the exposure time was only 20-minutes, however, findings from the current study demonstrated that constant exposure to the only vibration has considerable influence on seated occupant alertness level. The findings observed in this study mirror those of the previous studies that have examined the effect of short-term exposure to whole-body vibration on wakefulness level[5, 6]. Moreover, this study does not include female participant. It would be beneficial to conduct a similar study on a group of female volunteers.

The assessment and guidelines of human body ride comfort caused by vibration are reasonably well founded in ISO 2631-1 (1997) International Standard[11]. Following that, the relevant weighting factor has been established to represent the human perception of vibration. Although the guidelines for health effect due to exposure to vibration are well documented, there is little quantitative research data available on the influences of vibration on seated human drowsiness. In many studies, the relationship between vibration and drowsiness has been assumed without supporting research[45] This study demonstrates a link between exposure to vibration and drowsiness, at least under these experimental conditions.

Conclusion

This is, to our knowledge, the first study to investigate the effects of whole-body vibration on seated human alertness and drowsiness. Our data clearly demonstrate that exposure to vibration has considerable influence on subjective sleepiness levels, and more importantly, human reaction times and lapses of attention. These findings need to be further consolidated particularly in relation to driving behaviour (steering entropy). This line of research can then assist in the development of practical and relevant guidelines for limitation of vibration exposure in the automotive industry, in an effort to reduce the burden of disease of road accidents.

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